# SOUTH DAKOTA
# I 29 Southbound

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# SOUTH DAKOTA
# I 29 Southbound

## 1. DESCRIPTION

| | |
|---|---|
| Location: | Southbound I 29 over railroad in Minnehaha County<br>Structure No. 50-180-155 |
| Open to Traffic: | October 2000 |
| Environment: | Normal over railroad |
| HPC Elements: | Girders, deck, and bent diaphragms |
| Total Length: | 171 ft 9-5/8 in |
| Skew or Curve: | $27^{o}$ skew |
| Girder Type: | AASHTO Type II |
| Span Lengths: | 54 ft 0 in, 61 ft 0 in, and 54 ft 0 in |
| Girder Spacing: | 11 ft 5 in |
| Girder Strand Grade: | 270 |
| Girder Strand Dia.: | 0.5 in |
| Max. No. of Bottom Strands: | 32 |
| Deck Thickness: | 9 in |
| Deck Panels: | None |

## 2. BENEFITS OF HPC AND COSTS

### A. Benefits of HPC

The high-strength concrete used in the girders allowed the number of girder lines to be reduced from five to four. This reduced both girder costs and construction time. The low permeability of the deck concrete should increase the service life of the deck and reduce future maintenance costs.

### B. Costs

$\$56.70/ft^2$ of deck surface area including width of barriers. Cost does not include bridge end items such as approach slabs. Bid cost of the girders and deck were $91,660 and $85,536, respectively.

## 3. STRUCTURAL DESIGN

| | |
|---|---|
| Design Specifications: | AASHTO Standard Specifications for Highway Bridges 1996 with 1997 and 1998 Interims |
| Design Live Loads: | HS 25-44 and alternate except HS 20-44 and alternate loading were used for bridge deck design and serviceability requirements |
| Seismic Requirements: | AASHTO Seismic Performance Category A |
| Flexural Design Method: | AASHTO Standard Specifications 9.17 |
| Maximum Compressive Strain: | 0.003 |
| Shear Design Method: | AASHTO Standard Specifications |
| Fatigue Design Method: | AASHTO Standard Specifications 8.16.8 |
| Lateral Stability Considerations: | Diaphragms at midspan and ends of each span |
| Allowable Tensile Stress | |
| —Top of Girder at Release: | $3\sqrt{f'_{ci}}$ = 277 psi |
| —Bottom of Girder after Losses: | $6\sqrt{f'_{c}}$ = 597 psi |
| Prestress Loss: | 28% |
| Method Used for Loss: | AASHTO Standard Specifications 9.16.2.1 |
| Calculated Camber: | 1.5 in at release<br>2.75 in final |
| Concrete Cover | |
| —Girder: | 1 in clear |
| —Top of Deck: | 2-1/2 in clear |
| —Bottom of Deck: | 1 in clear |
| —Other Locations: | 2 in clear |
| Properties of Reinforcing Steel | |
| —Girder: | ASTM A 615 Grade 60, uncoated |
| —Deck: | ASTM A 615 Grade 60, epoxy coated |
| Properties of Strand | |
| —Grade and Type: | Grade 270, low relaxation |
| —Supplier: | — |
| —Surface Condition: | — |
| —Pattern: | Fourteen strands draped from 40% of span for both span lengths |
| —Transfer Length: | $1.5(f_{si}/f'_{ci})d_b$-4.6 |
| —Development Length: | AASHTO Standard Specifications 9.28 |

## 4. SPECIFIED ITEMS

### A. Concrete Properties

| | Girders | Deck |
|---|---|---|
| Minimum Cementitious Materials Content: | — | — |
| Max. Water/Cementitious Materials Ratio: | — | — |
| Min. Percentage of Fly Ash: | — | 10% (1) |
| Max. Percentage of Fly Ash: | — | 10% (1) |
| Min. Percentage of Silica Fume: | — | — |
| Max. Percentage of Silica Fume: | — | — |
| Min. Percentage of GGBFS: | — | — |
| Max. Percentage of GGBFS: | — | — |
| Maximum Aggregate Size: | — | — |
| Slump: | — | — |
| Air Content: | — | — |

(1) 10 percent of the cement was required to be replaced with Class F fly ash at a ratio of fly ash to cement of 1.9:1.0 by weight.

| | | |
|---|---|---|
| Compressive Strength | | |
| —Release of Strands: | 8520 psi | — |
| —Design: | 9900 psi at 28 days | 4500 psi at 28 days |
| | | |
| Chloride Permeability: (AASHTO T 277) | — | — |
| ASR or DEF Prevention: | — | — |
| Freeze-Thaw Resistance: | — | — |
| Deicer Scaling: | — | — |
| Abrasion Resistance: | — | — |
| Other: | Type II cement | Type II cement |

## B. Specified QC Procedures

| | |
|---|---|
| **Girder Production** | |
| Curing: | — |
| Internal Concrete Temperature: | — |
| Cylinder Curing: | — |
| Cylinder Size: | 4x8 in |
| Cylinder Capping Procedure: | — |
| Cylinder Testing Method: | — |
| Frequency of Testing: | — |
| Other QA/QC Requirements: | — |
| **Deck Construction** | |
| Curing: | Linseed oil based emulsion curing compound followed by wet burlap, soaker hoses, and polyethylene sheeting for 7 days. See Section 11 for details. |
| Cylinder Curing: | — |
| Cylinder Size: | 6x12 in |
| Flexural Strength: | — |
| Other QA/QC Requirements: | — |

# 5. CONCRETE MATERIALS

## A. Approved Concrete Mix Proportions

| | Girders | CIP Deck |
|---|---|---|
| Cement Brand: | South Dakota | — |
| Cement Type: | II | II |
| Cement Composition: | — | — |
| Cement Fineness: | — | — |
| Cement Quantity: | 680 lb/yd$^3$ | 590 lb/yd$^3$ |
| GGBFS Brand: | — | — |
| GGBFS Quantity: | — | — |
| Fly Ash Brand: | — | Coal Creek, Underwood |
| Fly Ash Type: | — | F |
| Fly Ash Quantity: | — | 124 lb/yd$^3$ |
| Silica Fume Brand: | Force 10,000 | — |
| Silica Fume Quantity: | 84 lb/yd$^3$ | — |
| Fine Aggregate Type: | — | — |
| Fine Aggregate FM: | — | — |
| Fine Aggregate SG: | — | 2.65 |
| Fine Aggregate Quantity: | 1200 lb/yd$^3$ | 1222 lb/yd$^3$ |
| Coarse Aggregate, Max. Size: | 3/4 in | — |
| Coarse Aggregate Type: | Quartzite | — |
| Coarse Aggregate SG: | — | 2.62 |
| Coarse Aggregate Quantity: | 1825 lb/yd$^3$ | 1634 lb/yd$^3$ |
| Water: | 190 lb/yd$^3$ | 255 lb/yd$^3$ |
| Water Reducer Brand: | Daracem 65 | WR-91 (Brett Admixtures) |
| Water Reducer Type: | A | — |
| Water Reducer Quantity: | 45.8 fl oz/yd$^3$ | 22 fl oz/yd$^3$ |
| High-Range Water-Reducer Brand: | Daracem 19 | — |
| High-Range Water-Reducer Type: | A and F | — |
| High-Range Water-Reducer Quantity: | 382 fl oz/yd$^3$ | — |
| Retarder Brand: | — | — |
| Retarder Type: | — | — |
| Retarder Quantity: | — | — |
| Corrosion Inhibitor Brand: | — | — |
| Corrosion Inhibitor Type: | — | — |
| Corrosion Inhibitor Quantity: | — | — |
| Air Entrainment Brand: | Daravair | AE-92 (Brett Admixtures) |
| Air Entrainment Type: | Saponified rosin | — |
| Air Entrainment Quantity: | 4.0 fl oz/yd$^3$ | As required |
| Water/Cementitious Materials Ratio: | 0.25 | 0.36 |

**B. Measured Properties of Approved Mix**

| | Girders | Deck |
|---|---|---|
| Slump: | 7 in | — |
| Air Content: | 4% ± 1% | 6.5% |
| Unit Weight: | 147.4 lb/ft$^3$ | 141.7 lb/ft$^3$ |
| Compressive Strength: | 12,280 psi at 7 days | — |
| | 14,065 psi at 28 days | — |
| Modulus of Elasticity: | 6200 ksi at 7 days | — |
| | 7200 ksi at 28 days | — |
| Chloride Permeability: (AASHTO T 277) | 158 coulombs at 2 days after curing at 100 $^o$F | — |

## 6. CONCRETE MATERIAL PROPERTIES

### A. Measured Properties from QC Tests of Production Concrete for Girders

Cement Composition: —
Actual Curing Procedure for Girders: Radiant heat
Maximum Girder Temperature: 140 $^{o}$F

Air Content, Slump, and Compressive Strength:

| Fabrication No. | Air Content, % | Slump, in | Concrete Age, days | Compressive Strength, psi |
|---|---|---|---|---|
| 1 | 6.3 | 6.5 | 35 | 15,270 |
| 2 | 6.6 | 7.0 | 33 | 13,010 |
| 3 | 6.6 | 7.0 | 28 | 13,842 |
| 4 | 7 | 7.0 | 28 | 14,956 |
| 5 | 6.1 | 7.0 | 28 | 12,730 |
| 6 | 7.4 | 7.0 | 28 | 11,455 |
| Average | 6.7 | 6.9 | 28 | 13,250 |

Curing Procedure for Cylinders:

### B. Measured Properties from QC Tests of Production Concrete for Deck

Cement Composition: —
Actual Curing Procedure for Deck: Soaker hose under wet burlap and plastic cover
Average Slump 2.5 in
Average Air Content: 6.8%
Average Unit Weight: 143 lb/ft$^3$
Compressive Strength: 6170 psi
Curing Procedure for Cylinders: —

## C. Measured Properties from Research Tests of Production Concrete for Girders

Compressive Strength:

All compressive strength values are in psi.

| Fabrication /Girder No. | Concrete Age, days | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 3 | 7 | 14 | 28 | 90 | 180 | 365 |
| 2/1 | — | 6770 | 9050 | 11,050 | 12,340 | 13,190 | 13,410 | 14,090 |
| 2/2 | — | 7310 | 10,020 | 12,670 | 13,880 | 15,190 | 15,190 | 15,690 |
| 3/1 | — | 8000 | 10,200 | 12,350 | 13,780 | 15,010 | 14,810 | 15,470 |
| 3/2 | — | 8380 | 10,140 | 11,650 | 14,080 | 14,950 | 15,530 | 16,150 |
| 5/1 (2) | 5240 | 7810 (3) | 9520 | 10,880 | 13,230 | 14,180 | 14,860 | 15,390 |
| 5/1 (4) | 5408 | 8790 (3) | 10,690 | 12,020 | 13,950 | 14,270 | 13,900 | 15,000 |
| 5/2 (2) | 6103 | 9540 (3) | 11,470 | 13,310 | 15,410 | 16,540 | 16,820 | 16,900 |
| 5/2 (4) | 6198 | 10,030 (3) | 12,110 | 13,605 | 15,690 | 15,940 | 16,270 | 16,650 |
| Average | — | — | 10,400 | 12,190 | 14,045 | 14,910 | 15,100 | 15,670 |

All results are the average values from three 4x8-in cylinders.
(2) Moist cure.
(3) Tested at concrete age of 4 days.
(4) Companion cure in the field with the girders.

Modulus of Elasticity:
(ASTM C 469)

| Concrete Age, days | 1 | 4 | 7 | 14 | 28 | 90 | 180 | 365 |
|---|---|---|---|---|---|---|---|---|
| Compressive Strength, psi | 5740 | 9010 | 11,090 | 12,450 | 14,460 | 15,450 | 15,600 | 15,920 |
| Modulus of Elasticity, ksi | 4980 | 5620 | 6260 | 6820 | 7130 | 7030 | 7060 | 7200 |

All results are the average values from four tests on 4x8-in cylinders.

Coefficient of Thermal Expansion (5): 7.74 and 7.74 millionths/$^{o}$F

(5) Measured using vibrating wire strain gages in two 6x6x12-in prisms stored in an outdoor environment.

Chloride Permeability:
(AASHTO T 277)

All chloride permeability values are in coulombs.

| Fabrication No. | Curing | Truck No. | | | | Average |
|---|---|---|---|---|---|---|
| | | 1 | | 2 | | |
| | | Sample No. | | | | |
| | | 1 | 2 | 3 | 4 | |
| 2 | Moist | 100 | 110 | 80 | 95 | 96 |
| 3 | Moist | 71 | 68 | 93 | 76 | 77 |
| 5 | Moist | 86 | — | 90 | — | 88 |
| | Companion | — | 93 | — | 87 | 90 |
| Average | | | | | | 88 |

## D. Measured Properties from Research Tests of Production Concrete for Deck

Compressive Strength:
All values of compressive strength are in psi.

| Series No. | Concrete Age, days | | | | | | |
|---|---|---|---|---|---|---|---|
| | 3 | 7 | 14 | 28 | 90 | 180 | 365 |
| 1 | 4450 | 5030 | 5840 | 6860 | 8120 | 9090 | 9590 |
| 2 | 3990 | 4440 | 5400 | 6330 | 7030 | 7690 | 8655 |
| 3 | 4420 | 5000 | 5870 | 6950 | 7930 | 8110 | 8705 |
| 4 | 4270 | 4970 | 5610 | 6530 | 7520 | 8100 | 8850 |
| 5 | 4420 | 5150 | 6070 | 7110 | 8360 | 8720 | 9420 |
| Average | 4310 | 4920 | 5760 | 6760 | 7770 | 8340 | 9040 |

All results are the average values from three 6x12-in cylinders.

Modulus of Elasticity:
(ASTM C 469)

| Concrete Age, days | 3 | 7 | 14 | 28 | 90 | 180 | 365 |
|---|---|---|---|---|---|---|---|
| Compressive Strength, psi | 4230 | 4800 | 5840 | 6640 | 7480 | 8400 | 9280 |
| Modulus of Elasticity, ksi | 4400 | 4550 | 5230 | 5620 | 5670 | 5960 | 6190 |

All results are the average values from three tests on 6x12-in cylinders.

Coefficient of Thermal Expansion (6): 7.64 and 7.58 millionths/$^{o}$F

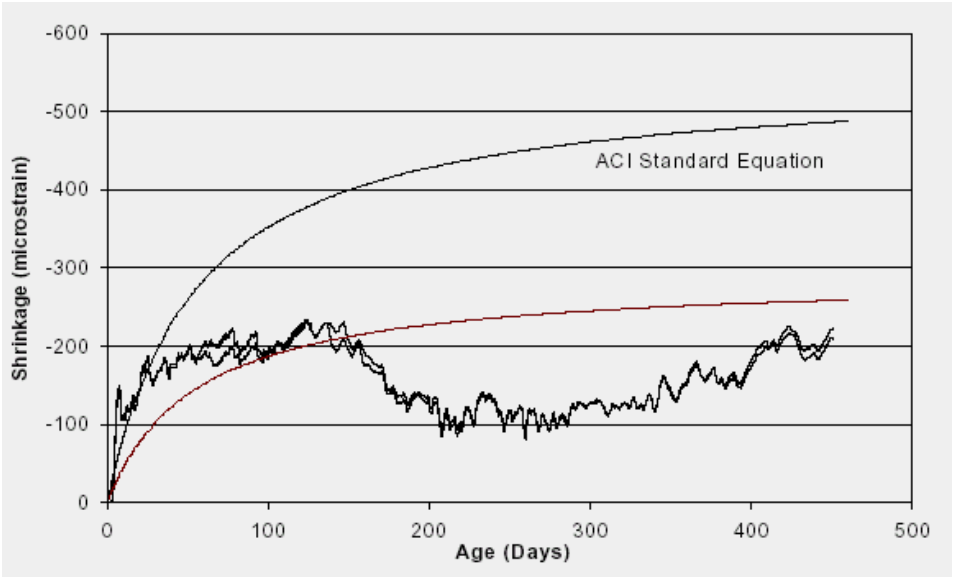
(6) Measured using vibrating wire strain gages in two 6x6x12-in prisms stored in an outdoor environment.

Chloride Permeability:
(AASHTO T 277)

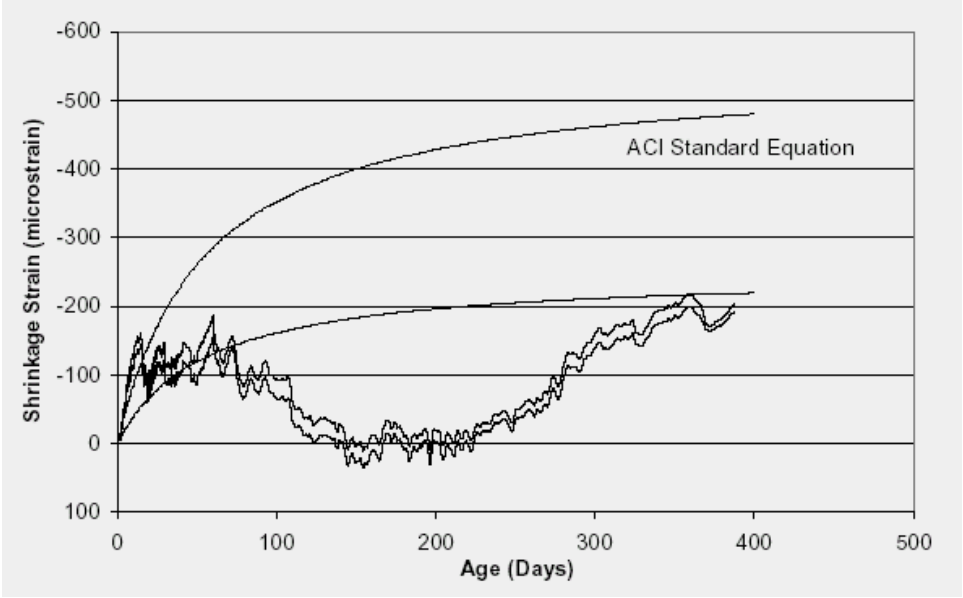
| Span | Permeability, coulombs |
|---|---|
| South | 844, 654, 827, 804 |
| Middle | 1548, 1396, 1279, 1394 |
| North | 877, 944, 1052, 1079 |
| Average | 1058 |

## 7. OTHER RESEARCH DATA

Shrinkage (7):



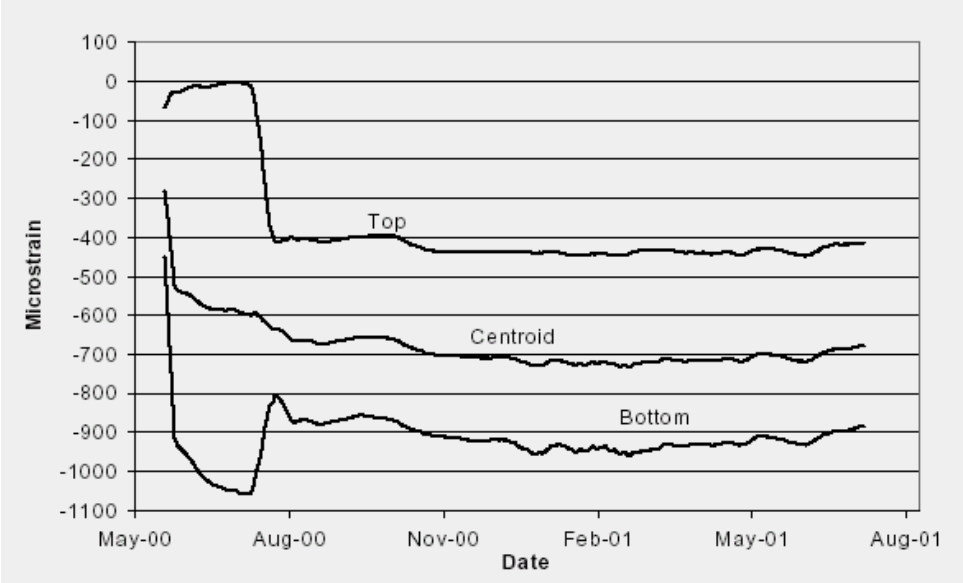

Girder Concrete




Deck Concrete

(7) Shrinkage strains measured using vibrating wire strain gages in two 6x6x12-in prisms in an outdoor environment.

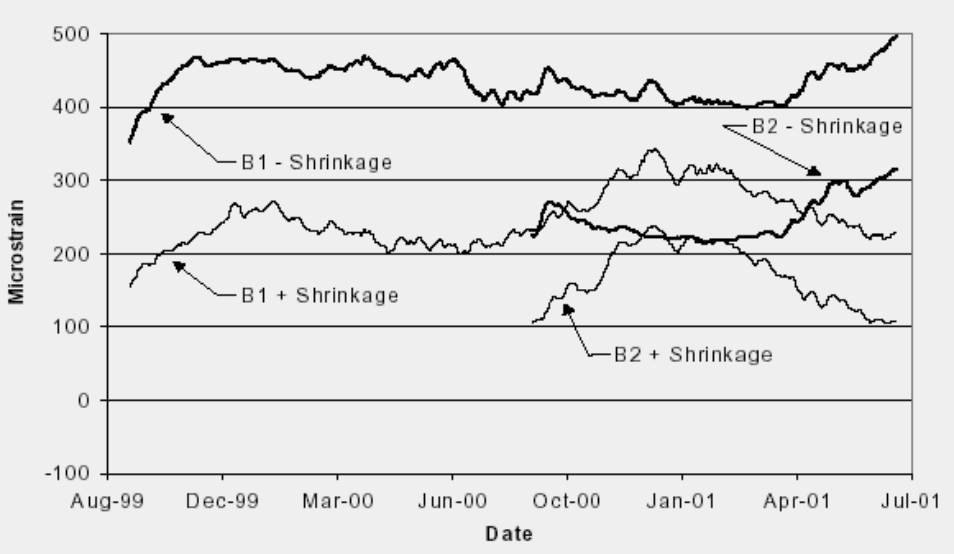
Girder Strains (8):




(8) Strains were measured at four vertical locations at midspan of two girders. Values at top, centroid, and bottom were determined by linear regression analysis from each set of four readings. The strains for each day were then averaged and the results from each girder averaged. See section 10 for location of gages.

Deck Strains (9):


Middepth Deck Strains at Midspan

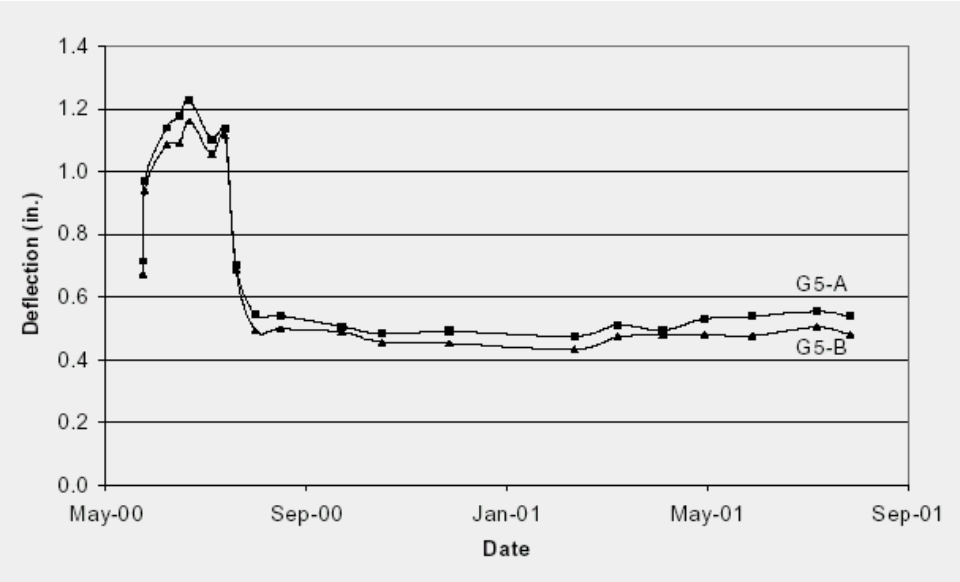



Middepth Deck Strains at the Bent

(9) Strains were measured at two vertical locations and then computed for the middepth locations. Bridge B1 is northbound. Bridge B2 is southbound. Strains are shown with and without shrinkage.

Temperatures:
Highest measured temperature of the deck during curing was 115 $^{o}$F about 27 hours after concrete placement.

Camber:




Midspan Deflection

| Camber (10) | Girder | |
|---|---|---|
| | G5-A | G5-B |
| Instantaneous Camber | 0.72 | 0.60 |
| Maximum Camber | 1.25 | 1.18 |
| Deck Placement Deflection | -0.45 | -0.42 |
| Average Deflections | | |
| Winter 2000 | 0.48 | 0.44 |
| Summer 2001 | 0.54 | 0.49 |

(10) All values are in inches. Positive values are an upward deflection.

## 8. OTHER RELATED RESEARCH

For the high-strength concrete used in the bridge girders, 12 mixes were made with various percentage replacements of the cement with silica fume and various water-cementitious materials ratios.

For the HPC used in the deck, ten mixes were investigated for both quartzite and limestone aggregates. In each mix, the percentage of cement replaced by fly ash was varied while keeping the water-cementitious materials ratio approximately constant at 0.40.

All concretes were tested for slump, air content, unit weight, compressive strength, modulus of elasticity, modulus of rupture, and chloride permeability. Test results are given in the final report listed in section 9.

Crack Survey:

In August 2001, an underside crack survey was conducted from the ground. Transverse cracks were observed. Nearly all the cracks exhibited calcium carbonate precipitation.

| Span | No. of Cracks | Spacing of Cracks, ft |
|---|---|---|
| North | 17 | 12.9 |
| Middle | 49 | 5.4 |
| South | 27 | 8.1 |

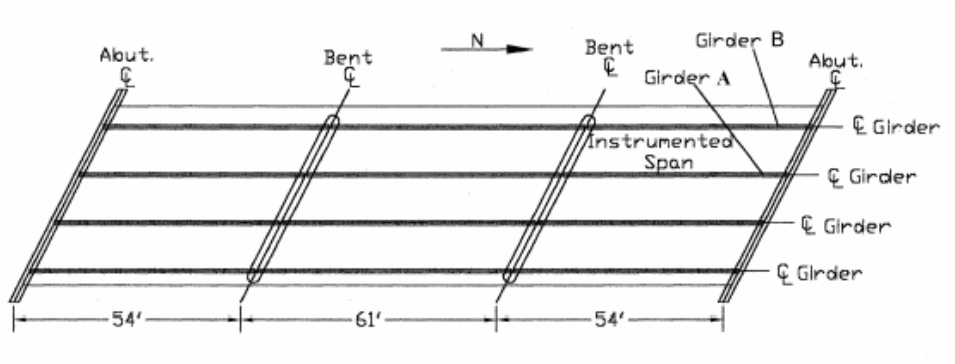
## 9. SOURCES OF DATA

Ramakrishnan, V. and Sigl, A., "Evaluation of High Performance Concrete in Four Bridge Decks as well as Prestressed Girders for Two Bridges," Report No. SD1998-06-F, South Dakota Department of Transportation, December 31, 2001, 180 pp. plus Appendices.

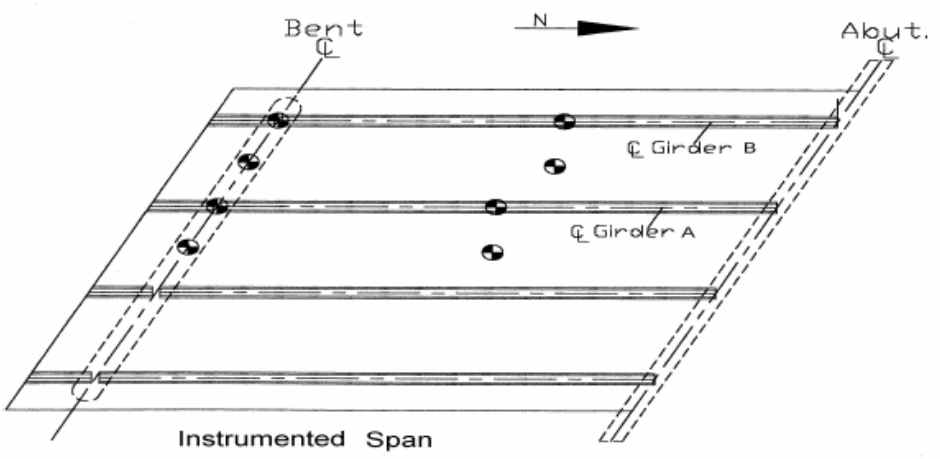
Hadly G. Eisenbeisz, State of South Dakota, Department of Transportation, Pierre, SD.

Daniel Strand, State of South Dakota, Department of Transportation, Pierre, SD.

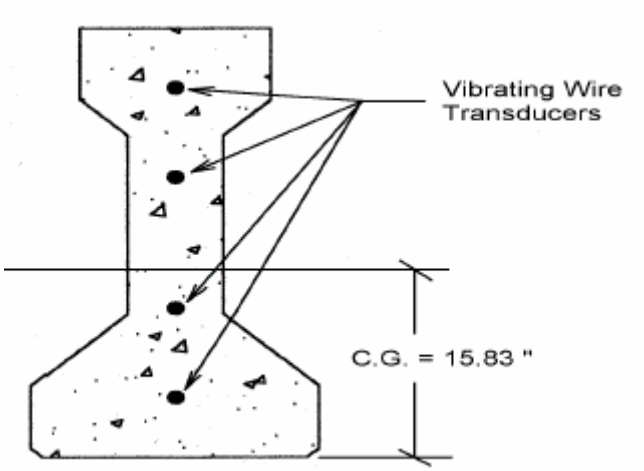
## 10. DRAWINGS



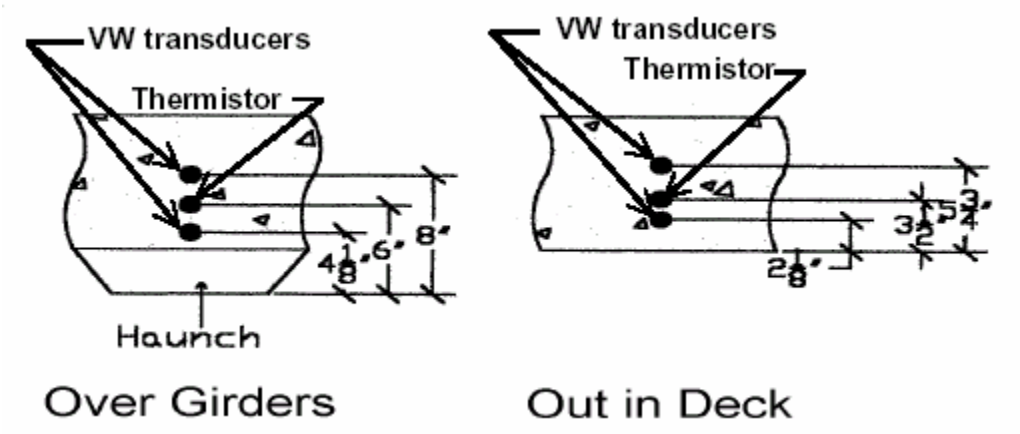

Girder Instrumentation Locations




Deck Instrumentation Locations




Location of Instrumentation in Girders




Location of Instrumentation in Decks

**STATE OF SOUTH DAKOTA**
**DEPARTMENT OF TRANSPORTATION**

**SPECIAL PROVISION**
**FOR**
**HIGH PERFORMANCE CONCRETE BRIDGE DECK**

**IM 029-3(82)84, PCEMS 3785**
**MINNEHAHA COUNTY**

**SEPTEMBER 17, 1999**

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The following specified revisions shall be made to Section 460 of the South Dakota Department of Transportation Standard Specifications for Roads and Bridges.

Change the following in Section 460.2.

**J. Fly Ash:** See the Special Provision for Fly Ash.

Add the following to Section 460.3A.

Concrete for the High Performance Concrete Bridge Deck shall conform to Class A45. Class F fly ash conforming to the Special Provision for Fly Ash is required to be used. The amount of cement that is to be replaced by the Class F fly ash shall be 10%. The ratio of substitution of fly ash to cement shall be 1.9:1, by weight. The mix design shall be volumetrically adjusted to accommodate the additional fly ash such that the water/cementitious ratio of the mix design remains the same.

Add the following to Section 460.3N.

High Performance Bridge Decks shall be cured as follows:

As soon as the bridge deck concrete has been struck off and finished by the finish machine, it shall be given a carpet drag finish with the carpet drag attached to the finish machine. Immediately after the bridge deck has been tined, linseed oil base emulsion curing compound shall be uniformly applied at the specified rate. Wet burlap shall be placed as soon as the concrete surface will support it without deformation. The burlap shall be kept continuously and thoroughly wet with soaker hoses for not less than seven days after placing the concrete. Polyethylene sheeting shall

be placed over the wet burlap and soaker hoses as soon as the concrete can be walked on without damaging it.

Add the following to Section 460.4.

METHOD OF MEASUREMENT: The high performance concrete bridge deck will be measured with neat line dimensions computed to the nearest 0.1 cubic yard.

Add the following to Section 460.5.

BASIS OF PAYMENT: The high performance concrete bridge deck will be paid for at the contract price per cubic yard. Payment will be full compensation for all labor, equipment, tools, materials, and other items required to furnish, place, finish and cure the High Performance Concrete.

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## 11. HPC SPECIFICATIONS (Cont.)

Special provisions were not provided for the girders.